THROUGH THE LABYRINTH
ANALYSING THE HISTORY OF GREAT BARRIER REEF SCIENTIFIC INVESTIGATION

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Introduction

Coral reefs today are one of the most profoundly threatened natural marine ecosystems on the planet. Throughout all tropic waters they are declining at an alarming rate, the result of excessive human pressure exacerbated by global warming and consequent rapidly accelerating climate change. Processes of deterioration were first noted in 1982 when unusually warm El Niño waters blanketed the Pacific Ocean and large areas of coral bleaching, the first stage of coral death, were reported (Glynn 1990). Then, further bleaching events were observed with increasing regularity in 1987, 1991, 1985, 1987, and 2002. The latest bleaching event of 2002 is still in progress, and the United Nations Global Coral Reef Monitoring Network (GCRMN) by 2002 had recorded serious losses ranging from an average of 17 per cent globally, and in places like Fiji the total death of close to 50 per cent (Wilkinson 2002).

The consequences of that collapse should be considered against the fact that, apart from the Great Barrier Reef along the eastern Australian coastline, all tropical coral reefs are in developing nations, and are a major form of subsistence for 600 million people. At the same time, many of those nations have neither the finances nor the expertise to exercise effective control.

In attempting to appreciate the full impact of that current global crisis it is of considerable value to examine the historical record of the scientific investigation of coral reefs: to gain, as it were, a perspective on how scientific study has gradually revealed ever astonishing knowledge of one of the most complex natural ecosystems on earth; and of the profoundly changing perceptions of coral reef ecosystems as the frontiers of myth, false assumptions and prejudice have been transcended. In proceeding to that understanding, the scientific study of the Great Barrier Reef is the world's paradigm example. Its fascinating history encapsulates the entire global record of coral reef investigation, and it remains the most important single location for the scientific study of the processes involved in understanding the functions of coral reef ecosystems.

The pattern of scientific investigation of the Great Barrier Reef

From the first sightings recorded in the journals of James Cook and Matthew Flinders, to the vast output of the late twentieth century literature, scientific investigation can be seen to fall quite readily into three, reasonably discrete, chronological periods:

1. The received tradition: nature as divine design: 1770–1870
2. Challenge of Darwinism: nature as process: 1870-1970
3. Science: a tool of conservation and management: 1970–2050?

This paper, then, will offer an explanation within those three categories, having necessarily to concentrate on salient developments. A fuller treatment, with much of the complex detail, can be found in the monograph 'The Great Barrier Reef: History, Science, Heritage' (Bowen and Bowen 2002).

PHASE 1: 1770-1870 - NATURE AS DIVINE DESIGN

Mystique of the Reef

Coral reefs first came to scientific attention in the era of overseas exploration when the major European powers moved beyond the Atlantic Ocean and entered the Pacific and Indian Oceans in their quest for colonies and resources for economic benefit. Beginning with Portugal and Spain following the Treaty of Tordesillas in 1494 when Pope Alexander VI divided the world between them into two exclusive maritime zones, coral reefs proved to be a major exploration hazard. Some time in the sixteenth century a Portuguese ship became wrecked at a now unknown place in the Indian Ocean and was marked on a map, also now lost. However, its name entered the lexicon of exploration as the 'abrolhos', a coinage from the injunction to Portuguese look-outs to 'keep your eyes open!' – *abre olhos!*

Early in the seventeenth century the Protestant Dutch ignored the papal decree and, with superior ships and firepower, sailed into the Indian Ocean and began the process of occupying the East Indies. On its maiden voyage in 1629 the *Batavia*, pride of the United East India Company (the VOC), was wrecked off the western coast of New Holland (today Western Australia), and in the mistaken belief that it was the same location on which the anonymous Portuguese ship was wrecked, it was named Houtman Abrolhos after the unlucky navigator, which it retains to this day.

Nothing recorded previously in the literature, however, had such a stunning impact on the European mind as the account of James Cook's disastrous collision in June 1770. Having completed the task of carrying a party of scientists to Tahiti to observe the transit of Venus in 1769 to improve longitude navigational tables in the period before the perfection of Harrison's marine chronometer, Cook then was ordered to sail westbound and attempt to find the mysterious east coast of the land mass previously charted by the Dutch, Abel Tasman in particular in 1642-44, and labelled New Holland.

Having circumnavigated New Zealand and then reached the east coast of the still unknown Terra Australis, Cook sailed north where he made a landfall at Botany Bay. Continuing north, unaware that he was entering the Reef lagoon, some 220 kilometres wide at its southern limit near the Tropic of Capricorn, his ship sailed into what becomes, essentially, a funnel, barely 60 kilometres across at its narrowest point around 15°S latitude. Lulled into a sense of false security by the calm waters, quite inexplicably, perhaps in an effort to return to England as soon as possible, now that the mission had been completed, he ordered the ship to continue during a calm moonlit night.

Towards midnight came a resounding crash, the ship's hull was smashed along the keel line, water flooded in, and it began to sink. Then followed a frenzy to stay afloat. The cannons were jettisoned, along with everything considered disposable, all hands went to the pumps in relays, including the two scientists Joseph Banks and Daniel Solander, while a midshipman and some of the crew passed a canvas sheet under the hull to fother the hole. Miraculously, Cook was able within a week to coax the Endeavour to the nearby coastline where it was beached, and for the next two months, repaired. He then decided to leave the lagoon at the earliest possible opportunity and was able to find a gap in the numerous ribbon reefs that border the edge of the continental shelf at what he gratefully named Providential Passage. Sailing north in the Coral Sea, Cook then turned to the west and sailed through Torres Strait to Timor, and then back to England.

When he eventually returned to England the following year, the Admiralty commissioned John Hawkesworth to write a popular account from Cook's journals to satisfy a 'travel-crazy' public. So popular was Hawkesworth's version of 1772 that it was immediately reprinted, issued in newspaper serials, cheaper pocket editions, and translated into many European languages. The French were naturally piqued and a campaign of vilification against Cook was launched, accusing him of using a previously unknown French map to navigate the Reef outside Torres Strait. One of the most violent verbal controversies in the history of maritime science followed. And that brought the Great Barrier Reef centre stage in the European mind.

Two particular features of Cook's experience engendered public wonderment: his account of the collision, and his description of the Reef with the sinister term 'The Labyrinth'.

His journal's words made startling reading to a population that had no conception of tropic waters. Once he had left through Providential Passage, he described the Reef from the ocean side, as

> 'a wall of Coral Rock rising almost perpendicular out of the unfathomable ocean ... the large waves of the ocean meeting with so sudden a resistance make a most terrible surf mountains high... 'A reef such as is here spoke of, is scarcely known in Europe' (Cook 1770).

Adding to the drama, and creating the mystique of the Reef was his allusion to the classical Greek legend of Perseus descending into the underground lair of the Minotaur in Crete, the labyrinth from which there was no escape. Perseus, however, was able to leave once he had slain the bull-headed monster because his lover Ariadne had given him a ball of twine to unwind as he searched, thereby enabling him to find his way back. Cook was not so fortunate, and it was the task of a sequence of navigators from Flinders in 1801-02 to Denham in 1860 to chart the complexity of a myriad of ribbon, patch and cay reefs in order to provide future ships with an 'Ariadne's Thread'.

Matthew Flinders was the next navigator to chart the Reef, having been sent in 1801, from the new foundation at Sydney of 1788, to complete the charting that Cook left off at Providential Passage. On his charts and journals published in 1814, belatedly after a period as a prisoner of war on Mauritius on his voyage back to England, Flinders changed Cook's name 'Labyrinth' to the 'Great Barrier Reef', and 'Terra Australis' to 'Australia', two neologisms that found ready acceptance.

That event, and many similar ones, created a serious scientific puzzle, as well as the more urgent navigational one. How, it was increasingly being asked, can such rocky structures rise almost vertically out of wide expanses of otherwise clear water? What are the biological processes that underlie the coral growths? And, in time, came the equally perplexing question: what are the geological processes involved?

In identifying the three main phases of the scientific investigation of coral reefs, then, all of which can be readily observed in the history of the exploration of the Great Barrier Reef, this paper will attempt to provide an Ariadne's Thread to enable the pattern to be followed.

The received tradition: taxonomy of Aristotle

With the voyages of Louis-Antoine de Bougainville in command of the *Boudeuse* in 1766-68, and James Cook in the *Endeavour* in 1769-71, a new era began since both ships had naturalists aboard: Philibert Commerson on the *Boudeuse*, and Joseph Banks and Daniel Solander on the *Endeavour*. From those voyages forward, all naval ships carried naturalists and they, like their commanders, were instructed to collect information that would contribute to understanding the origin and formation of coral reefs.

At that time, however, all naturalists were constrained to interpret nature within the context of the received tradition from the time of Aristotle (384-322 BC) whose incredibly detailed study of life forms in a number of works - *Inquiry into Animals, On the Generation of Animals, The Parts of Animals and The Study of Plants* – were the foundation documents of all natural history until the eighteenth century.

In his main work, known conventionally by its Latin title *Historia animalium*, Aristotle presented a classification of nature in which all phenomena were arranged in ascending order on a 'ladder of nature', a *scala naturae*. Following his system of division by appearances and mode of reproduction, inert rocks and other lifeless forms were placed at the lowest level, and the ladder then ascended in orderly fashion through simple plants with no apparent sensitivity to those that display some response, to indeterminate forms that could be either plant or animal - and he instanced sponges and sea-squirts - rising up to simple cold-blooded animals, then to the sanguinous, and finally to mankind at the pinnacle.

That system of classification, the *scala naturae*, lasted for more than two millennia, right into the middle of the eighteenth century, and was the theoretical framework within which all scientific investigation proceeded. Although not, it must be noted, without growing doubt, and at times and places, considerable dissent.

The new scala naturae: the Great Chain of Being

In the fifth century AD, however, a major revision had been made to Aristotle's *scala naturae*. And to understand that new development it is necessary to look, for a moment, at Aristotle's theory of creation.

In all societies, at all times and all places, the mystery of the origins of life, the earth and the heavens has been a consuming quest of metaphysical thinkers. Aristotle was one of the first in that speculative tradition, and following his relentless system of logical inquiry into cause and effect, he came to the conclusion that infinite regression had to arrive at a First Cause, beyond which further conjecture was impossible. So, the origin of all existence was presented as coming from some mysterious force, the 'First Mover', *to proton kinoun*. And, from that starting point, Aristotle was able to construct his great taxonomy of all material phenomena: inorganic earth, plants, animals.

The rise and institutionalisation of Christianity, however, largely due to the influence in the fifth century AD of the great church father Saint Augustine, replaced the hypothetical and immaterial First Cause with a very anthropocentric Creator God revealed in the Book of Genesis in which the *scala naturae* was believed to have appeared, in its entirety, in the six days of creation. Moreover, the original creation included all forms: all rocks, plants and animals. It was, in classical thought, a *plenum formarum*: a plenitude of forms, all present at the beginning and still in existence to the present day.

And yet a further change of name came. Since it was a divine creation by God Himself, (there is little gender sensitivity in the Old Testament), the *scala naturae* became the Golden Chain, or the Great Chain of Being, and that formed the framework of all natural history throughout the Middle Ages and the Renaissance.

In the early seventeenth century a new spirit of inquiry began with the formation of scientific societies of which two became pre-eminent: the Royal Society of London chartered by Charles II in 1662, followed by a French equivalent founded by Chief Minister Colbert in 1666 as the Acadèmie des Sciences. The Royal Society of London had been founded quite explicitly on principles of empirical inquiry into nature, as urged by Francis Bacon in his several works between 1605 and 1620 which should, in his words, lead to a renovation of knowledge. Its motto set the theme: *Nullius in verba* ('trust nothing in words'), its first historian describing its purpose, by means of empirical observation and experiment on nature, 'to follow all links of this chain [of Divine Creation], till all their secrets are open to our minds' (Sprat 1667).

Quest for a 'natural' taxonomy

The Great Chain of Being, then, became the unquestioned framework within which scientists pursued their investigations. The Bible was the authority and adherence to its teachings, particularly in science, was closely monitored in Catholic regions by the Inquisition, and in Protestant nations by their religious police, the faculties of theology in the universities. Heresy was a serious crime.

At the same time, to many scientists, the divine design of nature seemed a self-evident fact. How else could such intricate architecture have come about other than from a supernatural deity? Not only was the Bible proof for the existence of a creator God through revelation to Abraham and Moses, nature itself was proof through its miraculous design. That belief, known as Natural Theology, guided all scientific research throughout the eighteenth century. As Joseph Banks wrote in his *Journal* of 1770, explaining his paucity of observations regarding corals, he had been unable to 'make proper observations on this curious tribe of animals' because he was 'so intirely taken up with the more conspicuous links of the chain of creation as fish, plants, birds &c., that it was impossible' (Banks 1770).

Following the foundation of the colony of New South Wales in 1788 it was essential for the coastline of the new country to be charted since all communication with the mother country, and elsewhere, had to be by sea, and the primary obligation was to search for the economic possibilities of minerals and plants. Beginning with Matthew Flinders in command of the *Investigator* in 1801, a sequence of Royal Navy ships continued the task of mapping the complexity of the Reef lagoon begun by Cook, today known to measure 350,000 square kilometres (similar in area to the four main islands of Japan, or Great Britain and Eire), with a ribbon reef front of 2000 kilometres, and containing 2904 separate ribbon, patch and coral cay reefs, along with over 200 rocky continental islands.

In the first surveys by Cook in 1770, by Flinders in 1801-02 and Philip Parker King in 1817-22, the naturalists were confronted by a seemingly anomalous biota. Banks and Solander aboard the *Endeavour* in 1770, Robert Brown and Ferdinand Bauer on the *Investigator* in 1801-02, and Alan Cunningham on the *Mermaid* in 1817-22, all of whom were botanists in that first phase, experienced considerable difficulty in identifying the plants from their catalogues: the *Hortus kewensis* prepared in London's Royal Kew Gardens by William Aiton, and the *Genera plantarum* from the Jardin des Plantes in Paris by the great botanical taxonomist Antoine de Jussieu.

As plants were collected and sent back to Kew for placing within the divine design, sometimes insuperable difficulties were experienced. In 1793 James Edward Smith, founder of the Linnean Society, while examining a collection of Australian plants sent to the British Museum, made the telling comments in *A Specimen of the Botany of New Holland* of his attempts to describe one of Australia's most beautiful trees, the Christmas Bush (Ceratopetalum gummiferum):

> 'When a botanist first enters on the investigation of so remote a country as New Holland, he finds himself as it were in a new world. He can scarcely meet with any certain fixed points from which to draw his analogies ... Whole tribes of plants, which at first sight seem familiar to his acquaintance, as occupying links in Nature's chain ... prove, in nearer examination, total strangers' (Smith 1793).

Equal difficulty was experienced in describing the animals, none at all of which matched those elsewhere in the known world. How could the kangaroo or the opossum fit into any prepared zoological structure devised in the British Museum of Natural History, or in the Paris Muséum d'Histoire naturelle? Or, even more bizarrely, the egg-laying mammals found only in Australia, the two monotremes, echidna ('spiny anteater') and duck-billed platypus?

By 1821 the first scientific society in Australia had chosen as their motto the Latin phrase *Quocunque aspicias hic, paradoxus erit.* Strictly, 'whatever you see here will be a paradox', but rendered by some of the colonial wits as 'In Australia, all things are queer and opposite.' And they had a case: the swans were black, there were ants that ate spiders, and in some fruits the stone was on the outside. Surely, said Darwin in January 1836 during his short stay in Sydney aboard the *Beagle* on its epoch making cruise of 1831-36, 'An unbeliever in every thing beyond his own reason might exclaim, Two distinct Creators must have been at work!' (Darwin 1839).

As the early naturalists travelled aboard the survey vessels, Joseph Jukes on the *Fly* in 1842, John Macgillivray aboard the *Rattlesnake* in 1847 (in company with the very young T. H. Huxley) and again on the *Herald* in 1855, their task was to continue the attempt to understand the strange flora and fauna of that separate creation, one as early as 1819 that led poet Justice Barron Field to consider Australia more like 'an after-birth, not conceived in the beginning,' but coming later as a consequence of Original Sin. And the kangaroo, he jested, appeared as a 'divine mistake' while God was resting, exhausted, on the seventh day! (Field 1819).

None the less, all naval naturalists performed their tasks with considerable skill, endeavouring to discover the 'designed' order underlying all plants and animals. There had to be some kind of underlying pattern of affinities into which all new discoveries could be placed, a process akin to collecting and placing postage stamps into a pre-printed, structured album. As late as 1870 Frederick McCoy, professor of natural history in the University of Melbourne declared in a public lecture that the task of scientists in Australia was to fit everything, 'the whole of the vegetables, the whole of the animals,

[into] one, great, complete, universal plan, which was conceived by the Almighty in the beginning.' The naturalists' task, he continued, was to discover those missing 'separate parts' of the divine plan unknown in the Old World and to compete the divine design and so arrive at 'the beauty and continuity of the chain' (McCoy 1870).

PHASE 2: 1870-1890 – NATURE AS PROCESS

Beginnings of dissent in Europe

Throughout the early colonial era a considerable investigation of the Great Barrier Reef had been conducted, both by the naturalists aboard the surveying ships and by gentlemen amateurs for whom natural history, and cabinet collecting, was a consuming passion. Beginning with Alexander Macleay (1767-1848) chief administrator of New South Wales, the Colonial Secretary, who established one of the first, and certainly the most extensive 'cabinets' in the early decades, natural history expanded rapidly. Macleay was also instrumental in organising a natural history society that led to the foundation of the Australian Museum in 1849, and to study of the Reef, particularly by his son William Macleay who led an expedition there in 1874.

It all was, however, random, opportunistic, and unfocused. Naval naturalists could only collect where the survey ship was moored while engaged in triangulating the coastline; resident gentry cabinet collectors often depended on young men who were employed to extend their collections, and then usually for specific items, such as various species of dried coral formations, shells, beetles or butterflies. The great problem was putting them into some kind of systematic order. And, of course, at the time, that meant into their proper place in the divine stamp album.

A devout Christian, William Macleay had engaged himself over a lengthy period in a fruitless attempt to create a taxonomy of divine design on an ingenious 'Quinary System' whereby all nature was linked by supposed affinities in clusters of five related categories. A fundamentalist like his father, William, however, was constrained to fight a rearguard action against a growing insurrection. As Australian biota became ever more widely studied, the Great Chain of Being came under ever increasing stress.

The year 1870, of course, did not witness a sudden *volte face.* Lines can not be drawn with precision across the continuity of historical events. But it does represent an historical moment when the growing body of dissatisfaction with divine design theory, and the progress of empirical science, as advocated by Bacon more than a century earlier, began to falter. Fatally.

In 1870 Australia was still a remote colony in the very antipodes of European science, with a total population of but two million. Given the immense difficulties of time and distance, there was a considerable lag between overseas developments and their arrival and adoption here. And to understand the impact of the Darwinian conception of nature as process, and not as a pre-ordained divine design, it is necessary to give a brief account of the changes that had been gestating in Europe for nearly a century.

It seemed that some final determination of the Great Chain of Being had been made when, after several decades, drawing from his extensive network of corresponding naturalists throughout Europe, Asia, the Americas and the Caribbean, Linnaeus was able to create a complete taxonomy of all life forms in his *Genera plantarum* of 1754, and the *Systema naturae* of 1758, all governed by divine design. Yet, even as he was perfecting the great design in Uppsala, Sweden, one of his most active correspondents, John Ellis of London, kept urging him to ease up on the divine aspect. When the *Systema naturae* appeared, Linnaeus, in a letter to Ellis, was still baulking and continued to cling to the now obsolete Aristotelian belief that corals were intermediate forms between plants and animals, termed *zoophytes* (Gk. *Zôon* + *phyton*, 'animal-plant'), setting out his belief in a letter of 1761 that zoophytes had a plant stem from which animals were generated through a mysterious metamorphic process 'granted by the Creator' (Smith 1821).

The first major revisions in our scientific understanding of coral reefs, following the pioneer work of André de Peyssonnel (1694-1759) and John Ellis (1710-1776), were made by Jean-Baptiste Antoine de Monet de Lamarck (1744-1829). Appointed to the Paris Muséum nationale d'Histoire naturelle in 1793 he began to exercise an immense - if fiercely debatable – influence on natural history. Lamarck's chair at the Muséum was for the study of the most abundant, and least understood group of all animals: those placed by Linnaeus at the end of the *Systema naturae* as *Insecta* and *Vermes*.

The task had defied all who went before: whereas the four major groups of vertebrates – mammals, birds, reptiles, fish – had been reasonably well organised, he complained that 'the class of insects and that of worms described by Linnaeus in the Systema naturae are extremely badly determined' (Lamarck 1800). An ingenious deviser of neologisms, such as 'biology' in 1802, he defined them negatively as 'invertebrates'.

In 1800, after just seven years, Lamarck published his first work on the systematics of invertebrates in which he set out a new *scala naturae* of 7 classes and 20 orders, arranged in descending order of degrees of perfection as molluscs, crustaceans, arachnids, insects, worms, radiata and coral polyps, increasing the number of classes to 10 by 1809 with the separate identification of annelids, cirripedes and infusorians.

Coral polyps, he observed, were the most imperfect since they alone had no alimentary canal, but instead 'a sac of greater or lesser length, [which] has only one opening—at once both mouth and anus'. Simple as it may seem, that was to constitute a major step forward in the morphology of coral polyps, and helped separate them from the larger group of 'zoophytes' and corallines. Moreover, his concept of 'perfection' in animal form at the time was a rank heresy, since he believed that coral polyps were 'perhaps, the ones with which nature began, while it formed all others with the help of much time and of favourable circumstances' (Lamarck 1800).

Lamarck went much further along his heretical path. He defied the Biblical prescription of a six day creation some 6000 years earlier as calculated and set out in the *Annales Veteris et Novi Testamenti* ('Records of the Old and New Testament') by Bishop James Ussher in 1650-54, and inserted in the margins of all Bibles printed thereafter. In the early 1750s those six 'days' had been defined by George Louis Leclerc, le Comte de Buffon, director of the Paris Jardin royal des Plantes, as 'stages', which drew an accusation of heresy from the Faculty of Theology in the Sorbonne. Buffon was forced to recant and state that he abandoned 'whatever concerns the formation of the earth in my book, and in general anything which could be contrary to the narration of Moses [in the Bible]' (Buffon 1753).

Lamarck, whose patron was Buffon, was equally unremitting in his belief in the immensity of time that existed before the present, and the traditional belief that the arrangement of all animal life represented any divine plan: it was, he argued, an evolutionary pattern, brought out quite explicitly in his major work of 1809, the *Philosophie Zoologique.* The discoveries of the New World, particularly the strange fauna found in Australia such as the kangaroo and the platypus had puzzled Lamarck. Arguing that even if scientists become able to determine an order of nature (*ordre naturel*), 'the classes which we are obliged to establish in it will always be fundamentally artificial divisions.' The existing system, he continued, was completely inadequate to deal with the platypus and the echidna which alone in the class Mammalia lay eggs. 'Already the Ornithorhyncus and the Echidna' he wrote, 'seem to indicate the existence of animals intermediate between birds and mammals. How greatly natural science would profit if the vast region of Australia and many others were better known to us!' (Lamarck 1809b).

Foreshadowing his revolutionary and controversial theory of transformism, Lamarck denied any natural great chain of being (*échelle de la nature*) and asserted that *la nature n'a réellement formé ni classes ni ordres, ni familles, ni genres, ni espèces constants, mais seulement des individus qui se succèdent les uns aux autres et qui resemblement à ceux qui les ont produits* (in reality, nature has formed neither classes, orders, families, genera, nor invariable species, but only individuals which follow one another and resemble those from which they have been generated) (Lamarck 1809a). Others increasingly followed such as Georges Cuvier, also in the Paris Muséum, who made a major taxonomic revision in his *Regne Animal* of 1816. But it was the work of Lamarck and his doctrine of transformism, followed by the natural history researches of Alfred Russel Wallace (1823-1913) in South-east Asia and Charles Darwin (1809-1882), as well as the geological theories of Charles Lyell (1797-1875) that had begun to create a period of instability in science and came to exercise a profound and lasting effect on the investigation of the Great Barrier Reef.

Impact of Charles Darwin

All coral reef science, and particularly that involving the Great Barrier Reef, was to be irrevocably changed with the publication of two seminal works by Darwin.

As a result of his experiences aboard the global voyage of the *Beagle* between 1831 and 1836, Darwin was led to ponder two of the great natural history controversies of his day:

1. Whether the ideas of James Hutton presented in his *Theory of the Earth* of 1795 concerning the activity of volcanoes and earth subsidence were valid explanations for the formation of coral reefs; and
2. Whether Lamarck was correct in his theory that animals changed their form and structure in response to environmental pressures.

As a consequence, he published two of the most important books in the history of coral reef science:

1. *Structure and Distribution of Coral Reefs* in 1842; and
2. *The Origin of Species by Means of Natural Selection* in 1859.

Ever since the bitter debates between Abraham Werner and the Neptunists on the one hand, and James Hutton and Charles Lyell and the Plutonists on the other, geological inquiry had been intensely focused on searching for an explanation of the formation of the earth. Hutton dismissed Werner's belief that volcanoes are merely irrelevant epiphenomena on the earth's surface, and argued they are an integral feature of earth formation, and that the activity of underground forces expressed in subterranean heat is the primary agent modelling the earth's surface.

In *Structure and Distribution of Coral Reefs* Darwin argued, following the ideas in James Hutton, and subsequently Charles Lyell's three volume *Principles of Geology* (1830-33), that the earth's crust oscillates over immense stretches of geological time, thereby denying Bishop Ussher's calculation of 6000 years as the age of the earth.

As the earth oscillates (anticipating the modern theory of isostasy), Darwin argued, dormant volcanoes are carried down under the surface of the oceans, and in tropic waters coral polyps build their immense limestone structures on them. Provided they subside no faster than the polyps could build, coral reefs thereby could appear in the otherwise clear, open spaces of the oceans, rising hundreds of fathoms from the depths. And that, Darwin believed, solved the geological problem of the abrolhos, and atolls, and barrier reefs – including the Great Barrier.

Controversy immediately broke out, led by a number of dissentients, chiefly Karl Semper of Würzburg from his field work in 1862 on Palau; mining engineer Alexander Agassiz in a number of voyages between 1881 and 1910, including his own expedition to the Great Barrier Reef in 1896; and John Murray as a result of his findings aboard the great oceanographic expedition of the *Challenger* between 1872 and 1876.

The critical test was to drill down through the atolls, or the barriers, and extract a solid coral core with a basaltic foundation. Absolute proof.

As a result the Great Barrier Reef, Fiji and the atoll of Funafuti were all drilled as overseas investigators gathered in Australia in efforts to confirm or deny the theory of Darwin. The technology of the times, however, precluded any final determination, and that geological aspect of reef formation remained inconclusive for more than a century, even though a great deal of energy and money was expended by Henry Richards, professor of Geology at the University of Queensland between 1925 and 1937. Finally, the US Atomic Energy Commission, in seeking a safe site for their thermonuclear detonations on the atoll of Enewetak in the Marshall Islands, reached basaltic bedrock on two sites at 1287 and 1411 metres in 1952. The nearby atoll of Bikini, site of earlier atomic bomb tests in 1946, remains permanently uninhabitable. After a century of controversy, Darwin's theory of coral reef formation was finally confirmed.

Organisms and environment: the conditions of existence

The *Origin of Species* had a far greater, and more immediate, impact on all science. In place of a fixity of species from the beginning of time, in a carefully constructed work Darwin argued in considerable detail that all biota respond to changes in environmental conditions: those resulting from interactions among other plants, animals, and habitat.

While the great disputes over natural selection and the processes of evolution (a word that never appears in *Origin of Species*, although it ends with the word 'evolved') raged across Europe and the Americas, two particular developments, both occurring in 1866, had an immediate impact on marine science, and coral reef investigation in particular.

Known as the 'Statesman of Darwinism', in 1866 Anton Dohrn succeeded in his quest to establish the world's first marine research station in the Bay of Naples, the famous Stazione Zoologica where the processes of marine science could be studied in terms of natural selection and the 'struggle for existence'. Already a region of historical investigation of corals made prominent by the work of the great French marine biologist Henri Milne Edwards, whose classic study of 1857, *Histoire naturelle des Coralliaires*, is one of the foundation documents in the history of coral reef science, the Stazione Zoologica became the exemplar for the foundation of other marine research stations, beginning with the Plymouth Biological Station in 1888, the German Biologische Anstalt Helgoland in 1892 – island site of the first investigations by Ehrenberg as early as 1833 - and similar establishments in France at Banyuls, Villefranche and Roscoff. A century later in 1996, the European Marine Stations Network counted a membership of 40. And, of course, similar stations began to appear in North America, the most recent probably being Mount Desert Rock off Maine also in 1996.

The other great development in 1866 was the publication of *Generelle Morphologie* by Ernst Haeckel (1834-1919), a zoologist at the University of Würzburg. While he was still concerned to establish a natural system of relationships in nature, he followed the Darwinian concept of descent with modification as the path of investigation, and not anything based on divine design. There is no such thing as a creator, he asserted. The realm of nature is solely the result of 'the necessary effects of existing matter with its inalienable properties and their continual motion in time and space.'

Haeckel's central organising concept was a neologism that occurs at the beginning of his *General Morphology* (page 8) and became a cornerstone of all biological science thereafter: ecology (Gk *oikos* + *logos*, 'home' + 'study of'). Defined as 'the science of the relations of the organism to the environment including the conditions of existence – organic and inorganic', it was to become adopted by all natural scientists with increasing enthusiasm, although not at first with any really deep understanding of its full explanatory potential.

Marine science in Australia in 1866, however, was still firmly under the domination of the cabinet collectors and Biblical fundamentalists. None the less, the infiltration of Darwinians had begun, the first being Gerard Krefft, who had been employed in the British Museum which had already reorganised its collection on Darwinian lines of classes, orders, families and genera. Unwittingly appointed by William Macleay who failed to detect Krefft's Darwinian sympathies, he was smartly fired in 1874 on fabricated charges of negligence after he attempted to remove the 'horrible mounted impossibilities' of the 'species hunters', and to rearrange the collection on evolutionary lines.

Darwinism, natural selection and ecology, however, had come to stay, even though their first foothold in the nascent colony was still precarious. Then came the much needed burst of vigour with the arrival at the Queensland Museum in 1879 of William Haswell (1854-1925), an incredibly energetic Scot who immediately plunged into ecological studies of the Great Barrier Reef with the first field expeditions to the central regions out from the township of Bowen (named after the first governor). Haswell soon moved to a chair of biological science at the University of Sydney in 1881, and from that position, and as president of the biology section of the Australasian Society for the Advancement of Science, Darwinism had come to stay. 'Biological research', he declared in his Presidential Speech of 1891, has undergone 'an illumination ... [from] the theories of descent and modification by natural selection' (Haswell 1891). Haswell began the process of training a continuing stream of Darwinian biologists. Unfortunately, very few were yet in the field of marine science.

Mer Island: the first ecological study of the Great Barrier Reef

Although Europe and North America had a number of marine research stations, and efforts had been made to establish them in Australia, including a plea in 1890 by William Saville-Kent, President of the Royal Society of Queensland, an English consultant who had been engaged to report on the rapidly collapsing pearl shell oyster industry in Torres Strait due to over-exploitation and lack of biological research, none were in existence. There was little interest by governments in supporting marine science, and in particular that relating to the Great Barrier Reef. Several years later that deficiency was again brought to government notice in 1898 when Edgar Waite, a zoologist at the Australian Museum, wrote in frustration in an official report that 'we know nothing of the habits of the fish we wish to secure and have small chance of suppling the deficiency that exists until we have established a Biological Research Station. Many of the countries of Europe, and America, richly endow such institutions . . .' (Waite 1899-1914).

Far from endowing marine research, governments and the public alike saw the Reef as a resource for relentless stripping, whereby everything possible was pillaged and brought close to extinction: whales, dugongs, fish, bêche-de-mer, copra, guano, sandalwood, even coral rock for manufacture into building cement. The concept of sustainability was still a century away.

It was left to a team from the Carnegie Institution in Washington DC to make the first intensive scientific investigation of the Great Barrier Reef on Murray Island in north-east Torres Strait in 1913. Known as Mer by its traditional owners, it is a small extinct volcanic island on the edge of the Australian continental shelf some 2.5 kilometres long by 1.5 wide, surrounded by a large reef flat with a rich coral growth extending to the perimeter where it then drops off rapidly into extremely deep waters of the Coral Sea down to 1000 metres, and then 2000.

Throughout the month of October 1913 a team led by Alfred Mayor and Reginald Daly made the first full-scale intensive study in the world of a coral reef on the lines of the new approaches of ecology and evolutionary development now being followed in Europe. Mayor intended to investigate two great, still unknown, issues: what are the biological processes involved in the formation and continuity of coral reef ecosystems? and what are the associated geological processes? Mayor dealt with the ecology, Daly the geology.

Everything possible was studied with the technology of the times: atmospheric composition, pressure, winds, sunshine; water chemistry, temperature, tides, currents, plankton; coral species distribution across the reef flat, polyp biology and nutrition; as well as all other biota found on the reef flat. Daly, a Canadian geologist at Yale, was fanatical in his search to prove Darwin's subsidence theory of reef formation, and made intensive studies of its composition, mystifying the inhabitants with his incomprehensible actions in collecting rocks from the reef flats. Later on Pago Pago, where he continued his quest with the use of a rather primitive drilling rig, the locals even waded out onto the reef flat offering fruit and vegetables, explaining that rocks were completely inedible!

In 1918 the world's first intensive study of a coral reef was published by Mayor as *Ecology of the Murray Island of the Great Barrier Reef* which served as a stimulus to Australians to attempt one themselves.

The second major world study of a coral reef: Low Isles Expedition 1928-29

Unfortunately, following the 1913 study of Mer, World War I precluded any further study of coral reefs, except for the United States which did not become involved until 1917 (thereby allowing Mayor to work on the US naval base site at Pago Pago).

Once hostilities were concluded and some measure of stability restored to a seriously disturbed world, a voluntary organisation was formed in 1923 to further the scientific study of the Great Barrier Reef from within the nation. The inspiration of Australia's first native born coral reef scientist, Henry Richards, professor of geology in the University of Queensland, it originated as a sub-group of the Royal Geographical Society of Queensland, designated the Great Barrier Reef Committee (GBRC). Richards had envisioned it as a body devoted to his consuming passion to confirm the Darwinian subsidence theory, although others in the Committee wished to see it concentrate equally on biological studies such as those begun on Mer.

There was, however, an insuperable difficulty. Australia at the time had very few marine biologists and no marine biological research station. Consequently, to conduct an Australian ecological survey on the new well-established scientific procedures derived from Darwin, Dohrn and Haeckel, it was necessary to turn to Britain for expertise. So, while the Great Barrier Reef Committee undertook the essential aspects of fund raising and organising the logistics of site selection and preparation, the planning and execution of the world's first intensive ecological study of a coral reef devolved upon the leadership of the Department of Zoology in Cambridge University, with the support of the British Association for the Advancement of Science and the Royal Society of London.

Planning was organised impeccably, and in July 1928 a team of six men and four women from Britain arrived in Brisbane to travel to the Low Isles, a small coral cay some 65 kilometres north-west of Cairns, latitude 16° 24' S. Led by marine physiologist Maurice Yonge, with some rotation of personnel from Britain, and visits from zoologists at the Australian Museum and the University of Queensland, they moved onto the two hectare (five acre) cay where several prefabricated timber-framed buildings had been erected by local volunteers. A laboratory, library, sleeping quarters and a kitchen were waiting, and for the following year, until September when the last few left, the research commenced in earnest.

With an extensive array of laboratory equipment, boats, tide gauges and other meteorological apparatus, every possible parameter was studied. Just as on Mer, measurements were made of the atmosphere and the surrounding waters while on the reef flat aquaria were set up, transects established with metal pegs and wire mesh enclosures. Generic contours of coral distribution were made around the cay, species identified, all possible marine biota were captured and described, even to the extent of using a primitive diving helmet like a dust-bin with a glass panel in front, and supplied through a garden hose from a motor car tyre pump. Depths of 6 metres (20 feet) were attained, chiefly by Tom Iredale, English-born conchologist on loan from the Australian Museum, who had never learned to swim. The cord lifeline was his link with safety. Iredale became Australia's greatest conchologist in that era.

Some of the most important experiments were made on the biology and physiology of the coral animals themselves, chiefly by Yonge and his assistant Aubrey Nicholls, and as a result some of the most significant advances to that time were made in the world's understanding of the processes involved in coral reef biology and ecology.

So huge was the body of data collected that, needing to be sent to a large number of specialists, it took 20 years to process. Those findings appeared in 62 separate reports by the British Museum of Natural History, (1930-50) along with a number of books and descriptive articles in popular science magazines. So concluded the world's first intensive study of the ecology of a coral reef, and the contribution was of the first order of significance. Today those reports constitute our most valuable evidence of the condition of the Great Barrier Reef seventy five years ago.

And there everything stopped. In 1929 the world economy collapsed in the Great Economic Depression, and when the first signs of recovery appeared in 1933 and 1934, Europe had moved into the nightmare decade of Fascism, Nazism and Communism and World War II. Coral reef investigation ceased and scarcely had the first Allied victories been won against Rommel's Wehrmacht in North Africa than Australia was inadvertently plunged into the Pacific War of 1941-45.

The Great Barrier Reef became a war theatre, its passages into the Coral Sea were mined, and virtually all maritime traffic was military: warships, troopships, cargo carriers. No coral reef science was conducted until the war ended, when it was revived by Ernest Goddard, professor of biology in the University of Queensland. Previously, in the 1920s, he had led small university groups to vacation studies on Palm Island near Townsville. In 1946 he attempted to revive coral reef science on Heron Island, much closer to Brisbane, where he began a small research station in a simple timber building. Tragically, having barely started, he died there of a coronary occlusion in January 1948.

PHASE 3: 1870-2050? CONSERVATION AND MANAGEMENT

Australia is the world's largest island continent, populated mainly by European immigrants whose emotional ties still remain almost entirely with Europe and the Western cultural tradition. Following the foundation of Sydney in 1788 new settlers looked back to Britain, and were always conscious of their isolation in the antipodes and the immense sea voyages involved for all communication – passengers and cargo.

Surrounded by vast stretches of water in both the Indian and Pacific Oceans, one of the great ironies of the first two hundred years of European settlement was the lack of any sustained interest in the sea. Ships were merely transport, boats were fishing trawlers or pleasure craft for weekend recreation. No profound involvement occurred with the mystery and excitement of the marine realm: Australia never had an Henri Milne Edwards, no James Dana, no Karl Semper. No maritime zone beyond the sixteenth century three-mile limit existed, incredibly, until 1979. Marine research stations were something that belonged to the northern hemisphere; in Australia the focus was on clearing the forests, importing sheep, cattle and European strains of wheat. And, sadly, profoundly disturbing native ecosystems in the process. No government was prepared to fund marine stations: visiting expeditions were welcome, but their interests in coral reefs and marine ecology were exotic activities indulged in by foreigners. And when the first really significant marine station was created it came, not by any far-sighted vision for the future, but entirely negatively by a panic-stricken government in a bid to win re-election from an increasingly disaffected public.

In the 1960s the conservative Australian government was becoming destabilised by two major influences. One was involvement in the hugely unpopular Vietnam War in which the government resolved to support the United States, the other was internal from the greatest environmental controversy the nation had ever witnessed. The anti-war movement led to huge protest marches in cities and towns around the nation; the environmental controversy created continuing protests and newspaper, radio and television headlines.

After Rachel Carson had electrified the United States in 1962 with her devastating exposé in *Silent Spring* of the insidious effects of wide-scale environmental damage by the agrichemical industry, the concept of the environment rose steadily into public awareness. One of the most disturbing signs of visible pollution was the increasing frequency of oil well blowouts, particularly in the Gulf of Mexico where Red Adair became a household name for his daring exploits in capping errant gushers and extinguishing wildfire blazes.

In March 1967 the supertanker *Torrey Canyon* crashed into a submerged rock off Cornwall and spilled 30,000 tons of crude oil into the sea which washed onto the south-west coast of England. Further tanker spills continued, and then in January 1969, on the screens of the newly-arrived colour television sets of the United States, a 25 kilometre (15 mile) discharge of black oil could be seen gushing out of a drilling rig in the blue waters of the Santa Barbara Channel onto the silver vacation sands of Santa Barbara County.

And, it was discovered in that context, that the Queensland Government in 1968 had secretly leased all of the Great Barrier Reef to six oil companies – in which many cabinet members had shareholdings – for oil exploration. When that was revealed in the press, the greatest environmental protest ever mounted in Australia began in the Commonwealth and Queensland parliaments, in universities, and by environmental action groups. The media had a rich harvest of ready-made reportage.

Although most Australians had never seen the Great Barrier Reef, it had always been a national icon, its image promoted from the beginning by the exploits of Cook, Flinders and the early navigators. In the first decade of the twentieth century it had been promoted as an idyllic paradise by the journalist Edmund 'Beachcomber' Banfield, and in the early tourist brochures. And, ever since its foundation in 1923 the GBRC had been steadily attempting to urge governments into creating and funding Reef research. With remarkably little response. Until 1969 and Santa Barbara.

Protests were so strident – unions banned any labour for wharves and supplies to the drilling rigs – that both the Commonwealth and Queensland Governments were compelled to institute Royal Commissions into the potential damage from oil drilling on the Reef. Discontent with the disasters of Vietnam grew, environmental deterioration continued, and oil spills were anathema to the Australian public.

Situated on the central section of the Reef coastline near 19°S latitude, Townsville is a marginal seat. Facing a national election in 1969 with a restless public, the incumbent conservative government suddenly discovered the need for a marine research station of international standard to research the ecology of the national icon, and to provide scientific data for its effective management. It promised $3 million for a first-class marine station, in Townsville. Added urgency came in March 1970 when the *Oceanic Grandeur* grounded in Reef waters and discharged an oil spill. And, when the Commissions prepared to conduct sittings and the collection of evidence, it was revealed that there were almost no coral reef scientists in Australia available to give expert advice. They had to be found overseas!

The Australian Institute of Marine Science

The conservatives retained government with the smallest margin ever recorded, and fulfilled their promise by establishing AIMS (as it is universally known) by Act of the Commonwealth Parliament in 1971. It was opened on a site at Cape Ferguson a little to the south of Townsville in 1978 and for the past 26 years has steadily grown into one of the leading marine science stations in the world, today with a staff of 150 scientists, technicians and administrative assistants.

From the start, it was recognised that very little was known about the fundamental aspects of coral biology and patterns of ecosystem interaction. The United States had begun a serious research program on Enewetak in the 1950s alongside their thermonuclear explosion tests with the creation of the Mid Pacific Biological Laboratories (MPBL), of which the most significant studies were on ecosystem energy flows by Eugene and Harry Odum. That provided a starting point for AIMS research, along with the pressing and obvious need to know exactly what coral species were within Reef waters. By 1986 the first taxonomy of Reef corals had been published, and in 2000 appeared the world's landmark coral taxonomy publications (Veron 1986). A large number of other distinguished research publications have also appeared covering a wide range of topics, some of which are in the front rank of coral science investigation.

Not only corals are found on coral reefs. Integral with reef ecology are the algae, fish, echinoderms, molluscs, plankton – the list is huge. Consequently, AIMS had to continue expanding into a large number of related specialties.

Fundamental research, however, was not to be the sole direction of scientific investigation of the Reef. Too many immediate problems were occurring, the most urgent of which was the Crown of Thorns (COTS) infestation that had begun sometime in the early 1960s when irregular, undocumented sightings began to appear. As the 1960s progressed the infestation continued, and eventually it was recognised, as it remains at the time of writing, an uncontrollable plague that continues to devastate large tracts of coral reefs. The several COTS research and control projects have accounted for the greatest single research expenditure on the Reef.

The COTS plague, however, was but one of a multitude of marine environmental issues that had been generating exponentially over the same period. The coral bleaching episodes beginning in 1982 were the symptoms of a deteriorating global environment, particularly noticeable in the marine realm. Since the 1960s Jakob Bjerknes and Charles Keeling had been sounding the alarm over rising atmospheric CO^2 concentrations, in part response to which the United States created the National Oceanic and Atmospheric Administration (NOAA). The southern oscillation phenomenon in the Indian and Pacific Oceans first observed by meteorologist Gilbert Walker in 1926, and named by Bjerknes the 'Walker Circulation', was discovered to be linked with the term *El Niño* used by Peruvian fishermen to describe the unseasonably warm waters that ruined their anchovy harvests. Bjerknes coined the word 'teleconnections' to account for those previously unknown linkages that connect climatic events across oceans. Renewed research into past records revealed it to have occurred as early as 1957. Since then there has been a massive effort by NOAA to investigate the El Niño Southern Oscillation phenomenon and AIMS has been involved, along with marine scientists at nearby James Cook University and from the Centre for Marine Studies in the University of Queensland whose research into coral bleaching, on its research station on Heron Island is of international significance.

Not only was climate part of the huge agenda to be dealt with at AIMS. While the Reef was appreciated to be part of the wider ocean system, there were also numerous immediate domestic issues to research: biocide discharge into rivers and reef waters from agriculture, increasing silting of estuaries and fringing reefs from excessive land clearing, deteriorating water quality, unsustainable fishing practices, increasing pressure from exploitative pressure groups such as land and tourism developers and tour boat operators.

The research programs of AIMS have become so numerous they are beyond the scope of this paper to entertain since they now cover virtually the entire spectrum of tropical marine research, both fundamental and applied. And, recently its research activities have extended into other marine areas, and into cooperation with international bodies including NOAA, the GCRMN and other international organisations involved in the current crisis of world-wide reef instability. At last, after more than two centuries, Australia had finally gained an international standard marine research station that in many areas is now leading the world.

The Great Barrier Reef Marine Park Authority

While Australia is now an internationally recognised leader in tropical marine science, it is also the world leader in coral reef management, exemplified in its approach to the Great Barrier Reef itself. Like AIMS, the Great Barrier Reef Marine Park Authority, known by its acronym GBRMPA, is a twin born in the same period of profound labour to rescue the Reef from exploitation and environmental damage – adventitious as well as deliberate.

Ever since its foundation in 1923 the GBRC had been attempting to raise the profile of the Reef to governments and scientists. Originally a small band of dedicated scientists, conservationists and amateur naturalists, it had maintained a steady stream of consciousness in nature magazines and in resolutions to government concerning specific issues – wanton destruction of birdlife, dynamite fishing by ruthless men, pillaging for tourist souvenirs and so on. At the same time, it supported research activities in geology and biology.

When, however, the issue of oil drilling came to the fore, the GBRC became extremely energetic and lobbied the Commonwealth Government vigorously to create some kind of environmental management body to preserve the Reef in as natural a state as possible. When the conservative government that created AIMS in 1971 was defeated in a federal election in 1972, the incoming Labour government moved to provide such a supervisory body with the passage of the *Great Barrier Reef Marine Park Act* in 1975. The politics of that period are complex, full of intrigue and excessive obduracy by the Queensland government of the time but eventually they became resolved and over the past decades, like AIMS, GBRMPA has grown into a highly complex, sophisticated organisation with a staff also of 150 persons (Bowen and Bowen 2002).

In 1981 the Great Barrier Reef was declared a World Heritage Area, and since then management has made that the datum from which all action must proceed. Since it is an international waterway, with a large number of stakeholders, it could not be declared a national park, because UNESCO guidelines require national parks to exclude most activities, particularly commercial ones. It became, therefore, a multiple use marine park, managed with extreme sensitivity and professional competence, having acquired an international reputation for excellence and to which marine park managers from around the world now travel for advice and inspiration.

The Authority, however, is not a research body itself. It acts today as a 'research broker' providing funds and facilities to scientists for acceptable, specified projects, not only from AIMS, but also from James Cook University located in Townsville, the Centre for Marine Studies in the University of Queensland in Brisbane, several departments in the University of Sydney and from universities and research organisations both Australia and world wide.

Perhaps the most fitting conclusion to this paper, having attempted a passage through the labyrinth of research approaches, would be to acknowledge the dedicated work of the Great Barrier Reef's most persistent and ardent champion, the journalist Edmund 'Beachcomber' Banfield (1852-1923) who lived the life of a self-proclaimed lover of nature on Dunk Island, one or the Reef's most beautiful places, from 1903 until his death there twenty years later.

From his simple cottage he sent out a stream of newspaper articles, and letters to authorities urging the preservation of the Reef in all its natural beauty, along with three books of deeply moving lyrical praise of the Reef and the intense joy to be gained from the simple contemplation of nature. Profoundly inspired by reading Thoreau's *Walden* he worked ceaselessly with his numerous professional contacts, including scientists and politicians, to preserve the Great Barrier Reef. Today the visitor can see his simple grave of fieldstone on the island with an epitaph from *Walden*: 'if a man hears a different drummer, let him step to the music which he hears.'

The music he heard urged him to conserve the simple beauty of nature. His special dream was for the Reef to become a 'great insular park ... not improved by formal walks or set in straight lines or lopped and trimmed according to the principles of horticultural art, but just a wilderness – its primitive features preserved; its excesses unrestrained; its waywardness unapologised for. In such a wilderness the generations to come might wander, noting every detail as it was in Cook's day and for centuries before' (Banfield 1908).

A century later that dream has become the mission of GBRMPA and the task now being discharged in the scientific investigation of the Great Barrier Reef by all those involved: to preserve as far as possible, one of the greatest and most beautiful ecosystems in the world.

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